Sports Turf Alternatives Assessment: Preliminary Results
INFILL MADE FROM RECYCLED TIRES

Massachusetts Toxics Use Reduction Institute
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Introduction

The Massachusetts Toxics Use Reduction Institute (TURI) conducts alternatives assessments as part of its overall mission to help Massachusetts companies, communities, and municipalities identify and implement toxics use reduction options that will provide safer solutions to the use of toxic chemicals.

TURI has received numerous requests for information about artificial turf fields as an alternative to natural grass fields. In response, TURI is developing an alternatives assessment for sports turf. Preliminary sections of the assessment are being published in the order in which they are developed.

The section presented here covers information on chemicals found in the most commonly used type of synthetic infill: crumb rubber made from recycled tires. The recycled tire material is often referred to as styrene butadiene rubber (SBR) as this polymer is widely used in tires; it is also sometimes referred to generically as crumb rubber. For clarity, in this document we refer to it primarily as "tire crumb."

Information for this section has been drawn primarily from government agency reports and peer reviewed literature. This information may be updated over time as new information becomes available.

Recycled tires: Material description

Tires can contain a wide variety of materials. In general, the principal material in tires is styrene butadiene rubber (SBR). Tires can contain a wide variety of intentionally added chemicals, as well as substances that may adhere to the tire during its useful life. Many of these chemicals pose health or environmental concerns.

The recycling process mixes many tires together, and the composition of the final infill product is not standardized. The chemicals found in one field may differ from those found in another, and even within a single field, a sample taken in one part of the field may not be representative of the chemicals present in another part of the same field.

Additives found in tires include stabilizers, fillers, and vulcanizing agents, among other chemicals. Vulcanization is a curing process in which additives are used to modify and strengthen a polymer by forming cross-links among polymer chains. For more background related to these materials and processes, see "Chemicals in Artificial Turf Infill: Overview."[1]

Chemicals in recycled tire crumb: Overview

The US Environmental Protection Agency (EPA) recently conducted a comprehensive literature review of studies that have identified chemicals in infill made from recycled tires. EPA's review included studies of facilities that convert tires into tire crumb, studies related to tire crumb turf and playground installation, and studies related to use of tire crumb turf and playgrounds. The review identified just over 350 chemicals or chemical categories that were discussed in existing literature on tire crumb.[2] The presence and amount of a given chemical can vary depending on the sample of tire crumb.

Table 1, below, shows the categories of chemicals considered by EPA to be of interest, with examples of individual chemicals in each category.[3] As shown in the table, broad categories of interest include metals, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and a variety of uncategorized chemicals including rubber curing agents. The broad category of SVOCs includes polyaromatic hydrocarbons (PAHs), phthalates, and chemicals that may be applied to the crumb rubber as biocides during the life of the artificial turf.

Table 1: Categories of chemicals found in tire crumb Literature Review by US EPA

Category[a]	Subcategory	Examples
Metals		Aluminum, arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc.
VOCs		Benzene, benzothiazole, hexane, naphthalene, styrene, toluene, xylenes.
SVOCs	PAHs	Anthracene, benz(a)anthracene, fluoranthene, naphthalene, phenanthrene, pyrene.
	Phthalates	Benzylbutyl phthalate, di(2-ethylhexyl)adipate, di(2-ethylhexyl)phthalate [a.k.a. bis(2-ethylhexyl)phthalate]
	Biocide product ingredients	May include quaternary ammonium compounds such as alkylbenzyldimethyl ammonium chloride; alcohol ethoxylate 6; or others.[b]
Other[c]		4-tert-(octyl)-phenol [a.k.a. 4-t-octylphenol], butylated hydroxytoluene

Sources: Thomas K, Irvin-Barnwell E, Giuseppi-Elie A, Ragin-Wilson A. August 2016. *Research Protocol: Collections Related to Synthetic Turf Fields with Crumb Rubber Infill.* US EPA, CDC and ATSDR. Accessed at https://www.epa.gov/sites/production/files/2016-08/documents/tcrs_research_protocol_final_08-05-2016.pdf, January 2, 2017. US EPA. December 2016. *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds: Status Report.* EPA/600/R-16/364. Accessed at https://www.epa.gov/chemical-research/december-2016-status-report-federal-research-action-plan-recycled-tire-crumb, March 21, 2017.

[a] Note: Categorization shown here follows categories used in EPA's August 2016 publication.

[b] Thomas et al. note these have been identified by the California Office of Environmental Health Hazard Assessment (OEHHA) as "potential turf biocides."

[c] This category includes "potential rubber curatives, antioxidants/antiozonants, and other chemicals reported in literature."

Chemicals in recycled tire crumb: Key categories of concern

Many of the chemicals found in tire crumb have known adverse effects on human health. This section briefly summarizes information on key chemical categories of concern that may be present in tire crumb.

Metals. A range of metals of concern can be found in tire crumb. For example, in its review of the literature, EPA identified 21 studies that examine the presence of lead in tire crumb.[4] These studies attempted to answer a variety of questions. For example, some studies measured lead content in tires, while others considered the amount that could leach into the environment, or attempted to simulate the amount of lead that could be extracted through gastric digestion if tire crumb were ingested. A few examples are shown in Table 2, below.

Lead is toxic to the brain and nervous system, and childhood lead exposure can cause irreversible damage to brain development. Lead levels such as those shown here do not violate existing federal regulatory standards, although in some cases they may exceed regulatory standards in other countries. However, no level of lead in infill is desirable. There is no threshold below which lead exposure is known to be safe.

Zinc is another example of a metal that has been flagged as a source of concern in tire crumb. Particular concerns have been raised regarding toxicity of zinc-containing leachate for aquatic organisms. The Connecticut Department of Environmental Protection (2010) expresses concern about aquatic toxicity, noting that "there is a high potential for artificial turf to leach acutely toxic levels of metals especially copper and zinc," and that "certain samples of crumb rubber also leached acutely toxic levels of cadmium, barium, manganese and lead."[5] Kanematsu et al. (2009) flags zinc as a particular concern for the potential effects of recycled tire materials crumb on water quality.[6] Bocca et al. (2009) and Marsili et al. (2015) both found high levels of zinc in samples of tire crumb infill, as shown in Table 2. Both of these studies note that these levels are orders of magnitude higher than the relevant Italian standard of 150 mg/kg.[7]

Table 2: Studies measuring lead and zinc concentration in tire crumb: examples

Study	Lead	Zinc	Notes
Bocca et al. 2009[8]	Range: 12 to 46 mg/kg	Range: 118 to 19,375 mg/kg (median 10,229)	The authors note that the "concentration range for each metal was wide with respect to the different samples analyzed, suggesting that metals were not distributed uniformly in the rubber granulates."
Simcox et al. 2010[9]	Range: <68.9 to 271 µg/g [equivalent to mg/kg]	Not covered in this report.	Study included 9 measurements at 5 artificial turf (AT) fields in CT. Study notes that lead concentrations are below the level considered by EPA to present a "'soil lead hazard' in play areas" (400 µg/g).
Marsili et al. 2015[10]	Range: 10.76 to 38.99 mg/kg	Range: 3,474 to 13,202 mg/kg	Study included samples from 9 AT fields in Italy (5 new and 4 from fields in use for 1 to 8 years).

Sources: Bocca B et al. 2009. "Metals contained and leached from rubber granules used in synthetic turf areas." *Science of the Total Environment* 407:7, 2183-90. Simcox et al. 2010. *Artificial Turf Field Investigation in Connecticut Final Report*. University of Connecticut Health Center (UCHC). Marsili L et al. 2015. "Release of polycyclic aromatic hydrocarbons and heavy metals from crumb rubber in synthetic turf fields: preliminary hazard assessment for athletes." *Journal of Environmental and Analytical Toxicology* 5:2.

Volatile Organic Compounds (VOCs) and Semi-Volatile Organic Compounds (SVOCs). A wide range of VOCs and SVOCs have been detected in tire crumb. One example is benzothiazole, a chemical used in rubber manufacturing. A number of studies identify benzothiazole as an important chemical that may be released from recycled tire products, and highlight this chemical as a potential concern for athletes' exposure via inhalation.[11]

Polyaromatic hydrocarbons (PAHs). Polyaromatic hydrocarbons (PAHs) are a group of chemicals, a number of which are known human carcinogens. People can be exposed to PAHs through a variety of routes, such as cigarette smoke and ambient air pollution. Highly aromatic oils used in tire manufacturing are an important source of PAHs in tire crumb. Marsili et al. (2015) found that the release of chemicals from tire crumb "represents a major contribution to the total daily intake of PAHs by different routes." Marsili et al. quantified the levels of fourteen PAHs in nine tire crumb samples, including five that had not yet been spread on playing surfaces and four from surfaces already in use. The total level of these fourteen PAHs combined ranged from just over 8,000 ng/g to more than 46,000 ng/g [equivalent to 8 - 46 mg/kg]. Considering the

subset of these PAHs that are known to be carcinogenic, the total level of carcinogenic PAHs ranged from 2,546 ng/g to 22,780 ng/g [equivalent to 2.5 - 22.8 mg/kg]. Comparing levels to Italian regulatory standards, Marsili et al. found that all the samples exceeded the regulatory limit for two of the PAHs, and that in certain samples, the levels were an order of magnitude above the regulatory limits. The most toxic PAHs identified in the tire crumb included benzo(a)anthracene, chrysene, benzo(a)pyrene, and benzo(ghi)perylene.[12]

Phthalates. Phthalate esters, used as plasticizers to increase the malleability of rubber or plastic materials, can also be found in tire crumb. A number of phthalates are reproductive toxicants. A number of studies have examined levels of phthalates in tire crumb.[13] For example, Plesser and Lund (2004) noted "significant quantities" of certain phthalates in tire crumb leachate, especially diethyl phthalate (DEP) and diethylhexyl phthalate (DEHP).[14] A recent study conducted in the Netherlands found that DEHP and di-isononylphthalate (DINP) were the phthalates present at the highest levels in the samples tested (median 7.6 mg/kg and maximum 27.2 mg/kg for DEHP, median 35 mg/kg and maximum 61 mg/kg for DINP).[15]

PCBs and other persistent organic pollutants. A few studies have tested for polychlorinated biphenyls (PCBs), as well as dioxins and furans, in tire crumb. Menichini et al. (2011) found that the sum of PCBs in the sample they tested was three times the Italian standard "for soils to be reclaimed for use as 'green areas,'" while the sum of dioxins and furans came to 2/3 this standard. (The measured levels were 0.18 mg/kg and 0.67×10^{-5} mg/kg, respectively.)[16] In a study published in 2017, the Dutch National Institute for Public Health and the Environment (RIVM) found PCBs present at a median level of less than 0.035 mg/kg and a maximum of 0.074 mg/kg. They provide some regulatory standards for comparison but note that the testing methods used in the study may not correspond to those required by some regulatory standards.[17]

Health implications of chemical mixtures

Assessing the possible health and environmental effects of tire crumb is complicated by the fact that the material contains a large number of chemicals. Exposure to low doses of multiple chemicals can have health effects that may not be predicted based on the expected effects of each exposure individually. For this reason, in some cases it may be more useful to consider the effects of a mixture of chemicals, rather than analyzing each chemical individually. This has been done to a limited extent in studies of occupational exposures to tire crumb; for example, a study of a tire shredding facility in Taiwan found evidence of occupational exposure to known or suspected carcinogens including styrene, benzothiazole, phthalate esters (DEHP and di-octyl phthalate), and PAHs such as naphthalene. The researchers also tested airborne particulates from the facility for mutagenicity, and found that they showed "a substantial presence" of mutagens.[18] Similarly, Vermeulen et al. (2000) compared two tire-shredding facilities, looking at the mutagenicity of dust and fumes found in each facility.[19]

Health effects of playing on tire crumb: federal and state research

A number of studies have examined the chemicals present in synthetic turf, with a particular focus on chemicals found in crumb rubber made from recycled tires. However, federal and state officials have identified a need for additional information.

The California Office of Environmental Health Hazard Assessment (OEHHA), an office within the California Environmental Protection Agency, is conducting a three-year study of the potential health effects of exposure to synthetic turf as well as playground mats made from recycled waste tires. The project began in June 2015 and will be completed in June 2018. In the study, OEHHA will review the existing literature on chemicals in synthetic turf and playground mats; analyze samples of new and used synthetic turf and playground mats; develop exposure scenarios; and publish a risk assessment based on this information. OEHHA will also develop plans for a possible future study that would examine people's actual exposures through measurement of biological specimens or use of personal monitors.[20]

At the federal level, three agencies – the U.S. Environmental Protection Agency (EPA), the Consumer Product Safety Commission (CPSC), and the Agency for Toxic Substances and Disease Registry (ATSDR) within the Centers for Disease Control -- have collaborated on an examination of tire crumb infill. In the first year of the study, the agencies conducted a comprehensive review of existing literature, established a protocol for future research, and collected samples of tire crumb from a variety of sources, among other activities. Next steps for the research include analysis of the samples and characterization of people's exposure. As background on the need for this study, the EPA website notes that, "Limited studies have not shown an elevated health risk from playing on fields with tire crumb, but the existing studies do not comprehensively evaluate the concerns about health risks from exposure to tire crumb."[21]

A large number of published studies have examined questions such as what chemicals are present in tire crumb, what chemicals may be released during use of an artificial turf field, the quantities of chemicals to which children and athletes may be exposed, and possible environmental effects of tire crumb infill. Some of these studies are risk assessments, which attempt to estimate the likelihood of health problems for people who are exposed to the field. Risk assessments are developed on the basis of a variety of assumptions about exposure, chemical uptake, and other factors.

Unlike risk assessments, epidemiological studies are designed to investigate possible links between people's exposures and actual rates of disease. According to the federal agencies' literature review, to date there are no published epidemiological studies related to artificial turf fields. A January 2017 report by the Washington State Department of Health provided some information on soccer players with cancer in the state of Washington, but was not designed to investigate possible links between exposure to artificial turf fields and risk of developing cancer.[22]

Boundaries of this chapter

As a reminder, this chapter *only* includes information on the chemicals that may be found in tire crumb infill and the some of efforts that are under way to assess possible health implications. Detailed information on routes of exposure and other factors can be found in other, more detailed summaries of the literature on tire crumb, such as the literature review published by the federal agencies mentioned above.

Technical characteristics of the infill, including durability, are not discussed here. Information on heat-related concerns are covered in a separate chapter. In general, all synthetic turf fields reach higher temperatures than natural grass fields, regardless of infill type.

Summary

In summary, tire crumb infill contains a variety of chemicals of concern. While ample information is available on the chemicals present in tire crumb and the health effects of these chemicals in occupational and other contexts, no direct research has been conducted to assess human health effects of playing on artificial turf containing tire crumb infill.

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[1] Toxics Use Reduction Institute (TURI). 2017. "Sports Turf Alternatives Assessment: Preliminary Results: Chemicals in Artificial Turf Infill: Overview." All TURI documents on artificial turf can be found at: http://www.turi.org/Our_Work/Home_Community/Artificial_Turf.

[2] US EPA. December 2016. *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds.* EPA/600/R-16/364. Accessed at https://www.epa.gov/sites/production/files/2016-12/documents/federal_research_action_plan_on_recycled_tire_crumb_used_on_playing_fields_and_playgrounds_status_report.pdf, February 6, 2017. Chemicals covered in this literature review are also listed in a spreadsheet format in US EPA. December 2016. "Literature Review and Data Gap Analysis Spreadsheet." Available at https://www.epa.gov/chemical-research/december-2016-status-report-federal-research-action-plan-recycled-tire-crumb, viewed February 6, 2017.

[3] Thomas K, Irvin-Barnwell E, Giuseppi-Elie A, Ragin-Wilson A. August 2016. *Research Protocol: Collections Related to Synthetic Turf Fields with Crumb Rubber Infill.* US EPA, CDC and ATSDR. Accessed at https://www.epa.gov/sites/production/files/2016-08/documents/tcrs_research_protocol_final_08-05-2016.pdf, January 2, 2017.

[4] EPA, December 2016.

[5] Connecticut Department of Environmental Protection. 2010. "Artificial Turf Study: Leachate and Stormwater Characteristics." Accessed at http://www.ct.gov/deep/lib/deep/artificialturf/dep_artificial_turf_report.pdf, February 15, 2017.

[6] Kanematsu M et al. 2009. "Characterization and potential environmental risks of leachate from shredded rubber mulches." *Chemosphere* 76:7, 952-958.

[7] Bocca et al., 2009. "Metals contained and leached from rubber granules used in synthetic turf areas." *Science of the Total Environment* 407:7, 2183-90. Available at https://www.ncbi.nlm.nih.gov/pubmed/19155051, viewed February 13, 2017. Marsili L et al. 2015. "Release of polycyclic aromatic hydrocarbons and heavy metals from crumb rubber in synthetic turf fields: preliminary hazard assessment for athletes." *Journal of Environmental and Analytical Toxicology* 5:2. Available at https://www.omicsonline.org/open-access/release-of-polycyclic-aromatic-hydrocarbons-and-heavy-metals-from-rubber-crumb-in-synthetic-turf-fields-2161-0525.1000265.php?aid=39265, viewed February 13, 2017.

[8] Bocca B et al. 2009.

[9] Simcox et al. [Also cited as CT (UCHC)]. 2010. Artificial Turf Field Investigation in Connecticut Final Report. University of Connecticut Health Center (UCHC). Available at http://www.ct.gov/deep/lib/deep/artificialturf/uchc_artificial_turf_report.pdf, viewed February 13, 2017.

[10] Marsili L et al. 2015.

[11] See, for example, Office of Environmental Health Hazard Assessment (OEHHA). 2007. *Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products.* Sacramento, CA: OEHHA. Accessed at http://www.calrecycle.ca.gov/publications/Documents/1206/62206013.pdf, February 21, 2017; Ginsberg G., Toal B., and Kurland T. 2011. "Benzothiazole Toxicity Assessment in Support of Synthetic Turf Field Human Health Risk Assessment." *Journal of Toxicology and Environmental Health, Part A* 74:17, pp. 1175-1183; Ginsberg G. et al. 2011. "Human Health Risk Assessment of Synthetic Turf Fields Based upon Investigation of Five Fields in Connecticut." *Journal of Toxicology and Environmental Health, Part A* 74.17, pp. 1150-74.

[12] Marsili L et al. 2015.

[13] See, for example: Kanematsu, M et al. 2009. "Characterization and Potential Environmental Risks of Leachate from Shredded Rubber Mulches." *Chemosphere* 76: 952-958. Nilsson, NH et al. 2008. "Mapping Emissions and Environmental and Health Assessment of Chemical Substances in Artificial Turf." Danish Ministry of the Environment, Environmental Protection Agency. Accesed at http://www2.mst.dk/udgiv/publications/2008/978-87-7052-866-5/pdf/978-87-7052-867-2.pdf, April 27, 2017. Plesser, T and Lund, O. 2004. "Potential Health and Environmental Effects Linked to Artificial Turf Systems: Final Report." Trondheim, Norway: Norwegian Building

Research Institute. Project #0-10820. Accessed at http://www.knvb.nl/downloads/bestand/7065/noorwegen-2004--potential-health-and-environmental-effects-linked-to-artificial-turf-systems, April 27, 2017. New York Department of Environmental Conservation (NYDEC). 2008. *A Study to Assess Potential Environmental Impacts from the Use of Crumb Rubber as Infill Material in Synthetic Turf Fields.* Accessed at http://www.dec.ny.gov/docs/materials_minerals_pdf/tirestudy.pdf, April 27, 2017.

[14] Plesser and Lund, 2004.

[15] National Institute for Public Health and the Environment (The Netherlands) (RIVM). 2017. *Evaluation of Health Risks of Playing Sports on Synthetic Turf Pitches with Rubber Granulate.* RIVM Report 2017-0016. Bilthoven, Netherlands: RIVM. Accessed at http://www.rivm.nl/dsresource?objectid=b2975294-848e-4f2e-8fec-973de037d0b2&type=pdf&disposition=inline, May 1, 2017.

[16] Menichini E. et al. 2011. "Artificial-Turf Playing Fields: Contents of Metals, PAHs, PCBs, PCDDs and PCDFs, Inhalation Exposure to PAHs and Related Preliminary Risk Assessment." *Sci Total Environ.* 409: 23, 4950-7.

[17] National Institute for Public Health and the Environment (RIVM), 2017.

[18] Chien, Y-C et al. 2003. "Assessment of occupational health hazards in scrap-tire shredding facilities." *Science of the Total Environment* 309:1-3, 35-46.

[19] Vermeulen, R. 2000. "Mutagenic profile of rubber dust and fume exposure in two rubber tire companies." *Mutation Research/Genetic Toxicology and Environmental Mutagenesis* 468:2, 165-171.

[20] California Office of Environmental Health Hazard Assessment (OEHHA). 2016. "Synthetic Turf Scientific Advisory Panel Meeting, February 8, 2016: Meeting Materials." Available at http://oehha.ca.gov/risk/SyntheticTurfStudies/pdf/Feb2016meetingpacket.pdf, viewed March 30, 2016.

[21] US EPA. 2016. "Federal Research on Recycled Tire Crumbs Used on Playing Fields." US EPA web page updated February 18, 2016. Available at https://www.epa.gov/chemical-research/federal-research-recycled-tire-crumbs-used-playing-fields, viewed March 30, 2016.

[22] Washington State Department of Health. 2017. *Investigation of Reported Cancer among Soccer Players in Washington State.* DOH Pub 210-091. Accessed at http://www.doh.wa.gov/Portals/1/Documents/Pubs/210-091.pdf, February 24, 2017. Also see Toxics Use Reduction Institute. 2017. "Exposure to artificial turf infill made from recycled tires: Comments on January 2017 Washington Department of Health report." Information resource accessed at http://www.turi.org/Our_Work/Home_Community/Artificial_Turf/Comments_on_Washington_Department_of_Health_Report, May 2, 2017.